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**ASSESSMENT OF BLISTER FORMATION
IN PICKERING 3 AND 4 REACTORS**

Report No. 87-6-K

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ABSTRACT

A previously developed computer model of hydride blister formation in pressure tubes, which produces quantitative estimates of the number of blistered tubes in reactors as a function of time, has been modified to incorporate recently developed hydrogen pick-up rate scenarios and modeled garterspring distributions. Pick-up rate scenarios can now be modeled as piecewise linear with time and also as correlated with ingot chemical analysis (in these cases for iron content). Computer experiments with the resulting model have been carried out for reactors currently scheduled for REFAB¹. These experiments show that the expected number of blistered tubes for future times is extremely sensitive to the pick-up rate scenario assumed. For example, the number of blistered tubes in Pickering 3 following twenty years of operation varies from eight to fifty depending upon the pick-up rate assumed. The work therefore, points to the need for establishing the real pick-up rates in reactor in order to establish the likelihood of blistering on pressure tubes.

¹ Repositioning of Endfittings and Bearings

job	file	date	report no.
84-139-451	823.21	March 19, 1987	87-6-K



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EXECUTIVE SUMMARY

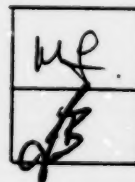
ASSESSMENT OF BLISTER FORMATION IN PICKERING 3 AND 4 REACTORS

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OBJECTIVE: Provide the current best estimate for the time dependence of the number of Zr-2.5 wt% Nb pressure tubes having hydride blisters in Pickering Units 3 and 4 which are currently scheduled for REFAB.

MAJOR RESULTS AND CONCLUSIONS

1. The previously developed computer model of blister formation in four garterspring units was refined to model new scenarios of hydrogen ingress (based on recent observations) and to use synthesized garterspring distributions which were developed to represent the garterspring position data available.
2. The computer experiments carried out for Pickering 3 and 4 show that the expected number of blistered tubes is extremely sensitive to the pick-up rate scenario; eg, for Pickering 3 the estimates range from eight to fifty blistered tubes following twenty years of operation depending on the hydrogen pick-up assumed.
3. This work points to the need for establishing the real hydrogen pick-up rates in reactor. Furthermore, it is suggested that the computer code be extended to include hydride blister growth and cracking.



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To Mr. D.W. Souther
Manager
Nuclear Systems Department

ASSESSMENT OF BLISTER FORMATION IN PICKERING 3 AND 4 REACTORS

1.0 INTRODUCTION

The assessment of the condition of the core of a reactor which is being considered for REFAB necessarily involves consideration of the probability of tube rupture due to blister formation following the REFAB operation. In order to carry out such an assessment, the best information available from the TRAC¹ program, from reactor measurements and observations of the condition of removed tubes and from other research programs must be analyzed and extrapolated using the best judgement possible. In order to assess the condition of any reactor core with respect to blister formation which is a step towards assessing tube rupture probabilities, we have developed a computer model which, by using distributed parametric information, yields an assessment of the number of tubes in a core which have exceeded the threshold hydrogen equivalent level required to begin blister formation at the points of contact with calandria tubes/1/.

It is important to note that the assessment of the threshold blister formation is a step towards assessing the pressure tube integrity under conditions of contact, but is not the whole story required to evaluate the probabilities of pressure tube rupture under such conditions. The current computer modeling must be extended significantly in order to arrive at such a probability assessment. Until such time as the modeling can be extended to include blister growth and cracking, the assessment of the number of tubes above the blister formation threshold can be used as one piece of information in the tube rupture assessment.

This report describes the modifications of the original computer model required to carry out the assessment of blister formation for two of the reactors being considered for REFAB: Pickering 3 and 4. The new computer model has been applied to assess the consequences of various scenarios of deuterium ingress behaviour over the years of interest for REFAB actions. The outputs of this assessment are the time dependencies of the probable numbers of tubes containing blisters in each reactor for the different scenarios.

2.0 THEORY AND THE DEVELOPMENT OF INPUTS

The model used in these computer simulations is the mathematical expression of the work done in the TRAC program. Its assumptions have been reported elsewhere/1/. Two major modifications were introduced to the existing computer code.

1. TRAC - Tube Response After Contact

The first modification concerns the treatment of the location of the gartersprings in these four reactors. Garterspring location distributions were developed on the basis of the sparse data available for Pickering 3 and 4. Special attention was paid to preserve the large peak at the design location in the garterspring position distribution and to incorporate the asymmetries in the displacements. It should be noted that the poor database required us to make many assumptions which may need modification when further observations become available. The development of these distributions is discussed in detail in Appendix A5.

The second major modification allows for more flexibility and sophistication in the representation of the hydrogen pick-up rate. The pick-up scenarios are modeled to be piecewise linear with time; furthermore, pick-up rates can be dependent upon the area of the pressure tube (inlet, centre or outlet contact area).

Two viewpoints underlie the development of hydrogen pick-up scenarios:

1. **Concern and Alarm:** The hydrogen pick-up rate increases dramatically at some point in the reactor life. The transition time at which the rate change occurs is probably temperature dependent and may depend upon the oxide reaching a critical thickness of 15 μm . Two pick-up scenarios which came under this heading have been used in these investigations: BW and 10. BW assumes a low pick-up rate till the oxide layer reaches 15 μm (15.6 years at the outlet area); when this thickness is reached a very high pick-up rate is assumed (5.25 ppm/yr). PU RATE 10 assumes a low pick-up rate up to ten years; beyond ten years a pick-up rate is assumed which is consistent with the observations on the pressure tube removed from P4K10.
2. **Creative Speculation:** The hydrogen pick-up rate is constant over time, but is related to the iron content in the pressure tube. This reflects recent information regarding apparent correlations between hydrogen pick-up rate and ingot iron content, especially for DG3 is based on this idea.

A complete discussion of the models for hydrogen pick-up is given in Appendix A3.

The treatments of the other inputs are discussed in Appendices A1 (hydrogen threshold), A2 (initial hydrogen content) and A4 (the spanlength time to contact relationship). For these inputs, the treatments are similar to those previously reported/1/.

3.0 COMPUTER MODELING RESULTS

3.1 Introduction

Not all the results of the different computer experiments will be discussed. Attention will be focused on intercomparisons of the results of the computer experiments; this provides insights into the dependency of blister formation on the input parameters.

The experimental tests discussed are tabulated in Table 1; the dependencies that will be discussed in detail are those on hydrogen pick-up rate, hydrogen threshold and specific reactor.

TABLE 1
EXPERIMENTAL TEST MATRIX

Reactor	Pick Up Rate	Threshold Scenario	Source of Spanlength Time to Contact Relation
P3	PU RATE 10	3	ABAQUS
	PU RATE BW	3	ABAQUS
	PU RATE DG3	3	ABAQUS
P4	PU RATE 10	3	ABAQUS
	PU RATE BW	3	ABAQUS
	PU RATE DG3	3	ABAQUS
	PU RATE BW	2	ABAQUS

3.2 Dependence on Hydrogen Pick-up Rates

In order to assess the effect of hydrogen pick-up rates on the number of blistered tubes, other variables were held constant. Figure 1 shows the number of blistered tubes as a function of time for Pickering 3 for three possible scenarios, PU RATES BW, DG3, and 10 described in Appendix 3. As shown, it indicates that Scenario PU RATE 10 would yield the greatest number of blistered tubes (about fifty) after twenty years of operation. Scenario PU RATE BW has more tubes with blisters than PU RATE DG3, but some tubes in the PU RATE DG3 scenario may have larger blisters because they exceeded the threshold for blister formation for a longer time. This has ramifications for risk assessment if blister size is crucial in determining blister cracking. The modeling of Pickering 4, as shown in Figure 2, indicates the same general behaviour as Pickering 3.

3.3 Blister Formation in Different Reactors

The role of other factors affecting blister formation can be assessed by holding the pick-up rate scenario constant. Figure 3 compares the results of the modeling of the behaviour of Pickering 3 and Pickering 4 assuming for both the PU RATE DG3 scenario. The differences in the number of blistered tubes in Pickering 3 and 4 are due to:

- Differences in the initial hydrogen content;
- Small differences in the iron concentrations leading to small differences in the pick-up rates.

As can be seen, the differences are not very substantial.

3.4 Influence of Hydrogen Threshold

A comparison has been made between the number of blistered tubes predicted with our current judgement of the most likely hydrogen threshold scenario (3.0) and the number of blistered tubes predicted with a more optimistic scenario (2.0). The comparison will depend on the specifics of the chosen hydrogen pick-up rate scenario; for Pickering 4 and scenario PU RATE BW, the results are shown in Figure 4 indicating that the change in threshold scenario (from 3.0 to 2.0) results in a positive shift of one year in the time required to reach a similar expected number of blistered tubes.

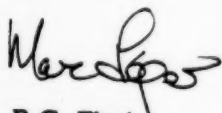
DISCUSSION AND CONCLUSIONS

1. In order to predict the number of blistered tubes in Pickering 3 and 4, information has to be provided for five inputs required in the computer model. The quality of this information was, in several respects, deficient.
 - the initial hydrogen content of the pressure tubes is relatively well-defined.
 - a wide range of hydrogen pick-up scenarios are now considered possible.
 - the very small database on garterspring locations in Pickering 3 and 4 may not be representative. It should be noted that for matter of convenience and because of lack of any data, the suggested garterspring location distribution is assumed to be the same for the central core, the intermediate channels and the outer channels. This was not the case for Bruce 6 and Pickering 7.
 - as noted in our previous report/1/, considerable uncertainty surrounds the hydrogen threshold value for blister formation.
2. The importance of the choice of hydrogen pick-up rate scenario has been demonstrated in this report. The estimates for the number of blistered tubes in Pickering 3 after twenty years range from fifty to eight depending on the choice of pick-up rate scenario. Therefore, it is extremely important that the "real" pick-up rate be identified as soon as possible. It is likely that the consequences of blister formation on pressure tube integrity are even more dependent upon pick-up rate scenario.
3. The influence of hydrogen threshold and initial hydrogen content on the number of blistered tubes is considerably smaller than the influence of the choice of hydrogen pick-up rate.
4. While the difficulties in this predictive exercise are acknowledged, it nevertheless remains our conviction that the results of the computer experiments reported here are the most accurate predictions of the number of blistered tubes in reactors Pickering 3 and 4 given the present state of knowledge. If more information becomes available, then the model can incorporate this new knowledge to refine the present predictions.

RECOMMENDATIONS

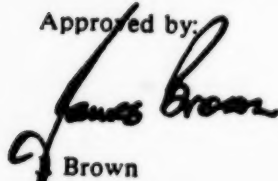
1. All possible methods of determining hydrogen pick-up rate for tubes in reactor should be explored as quickly as possible. The strong dependence of blister formation on this parameter indicates that more information is required.
2. Modeling should be extended to the effects of blisters on pressure tube integrity. Only fractured blisters pose a problem for the integrity of the pressure tubes and therefore, the modeling has to be carried out to the point where it is most useful.

Reviewed by:



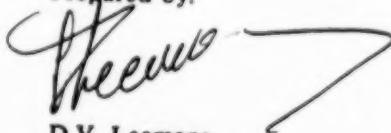
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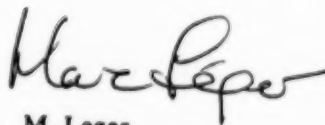


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REFERENCES

1. M. Leger and D.V. Leemans, "A Study on Hydride Blister Formation in Bruce 3 and 4 and Pickering 5 and 6", Ontario Hydro Research Report, 86-153-K.

COMPARISON OF PU RATES

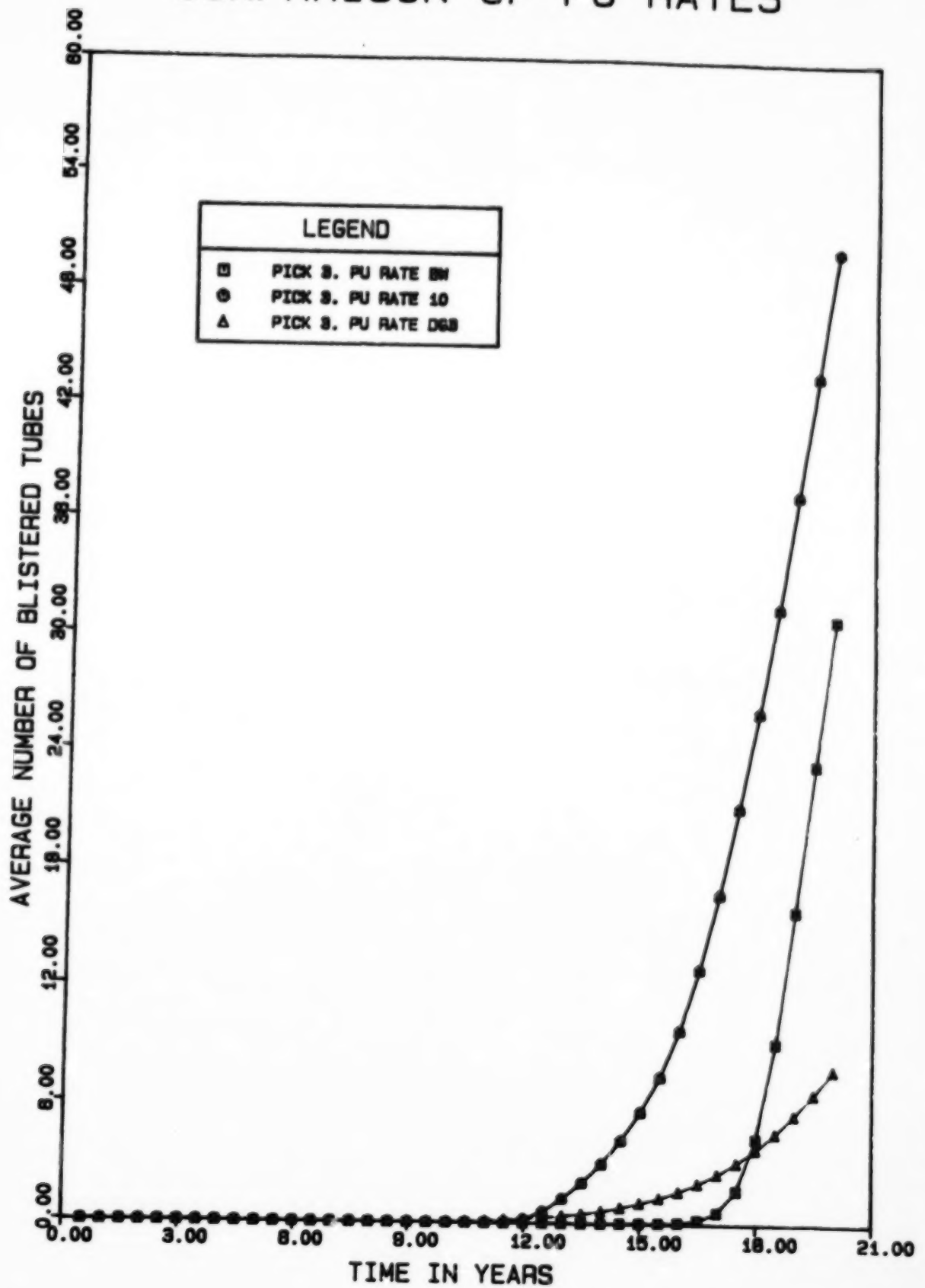


FIGURE 1

COMPARISON OF PU RATES

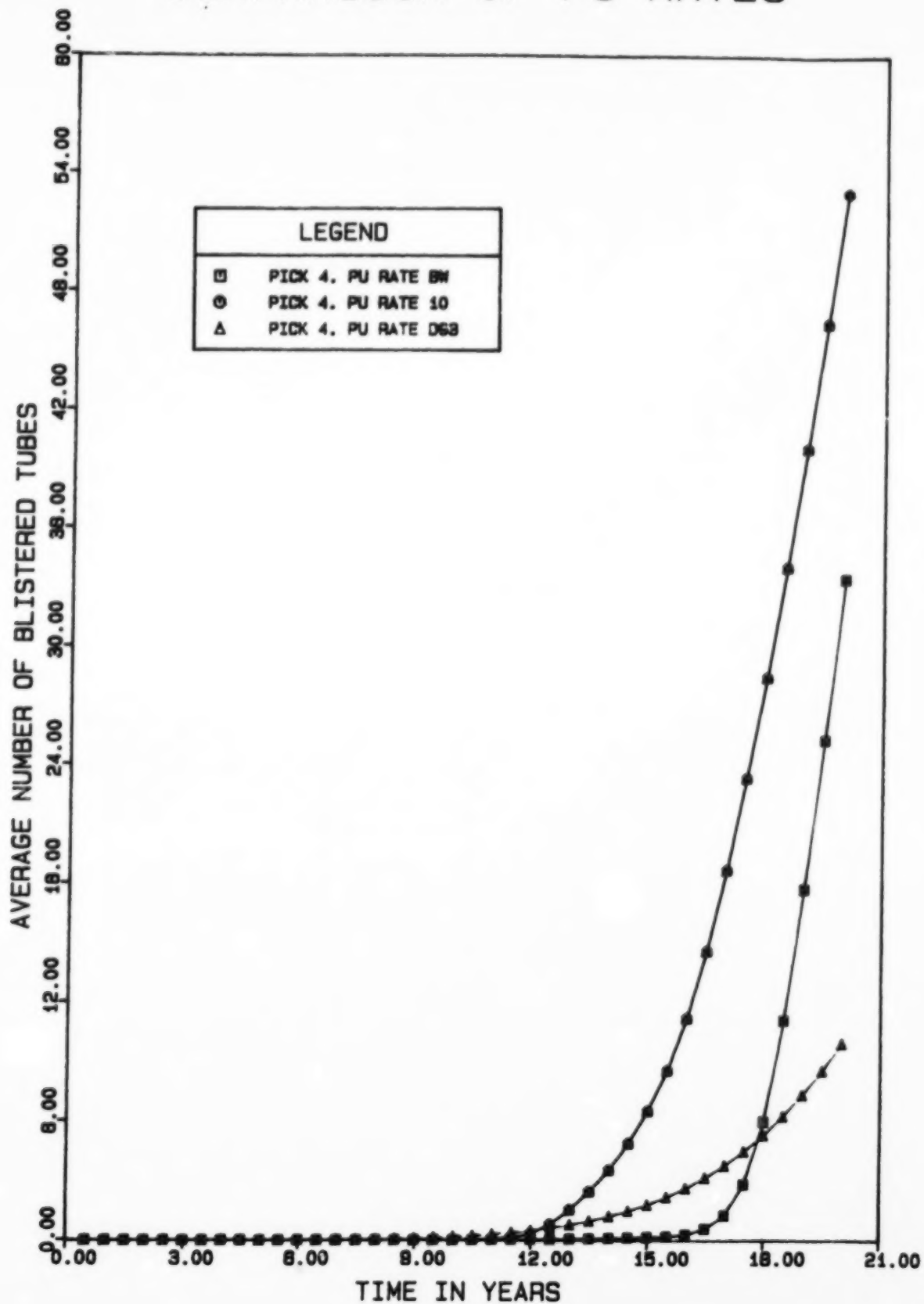


FIGURE 2

COMPARISON OF REACTORS: PU RATES DG3

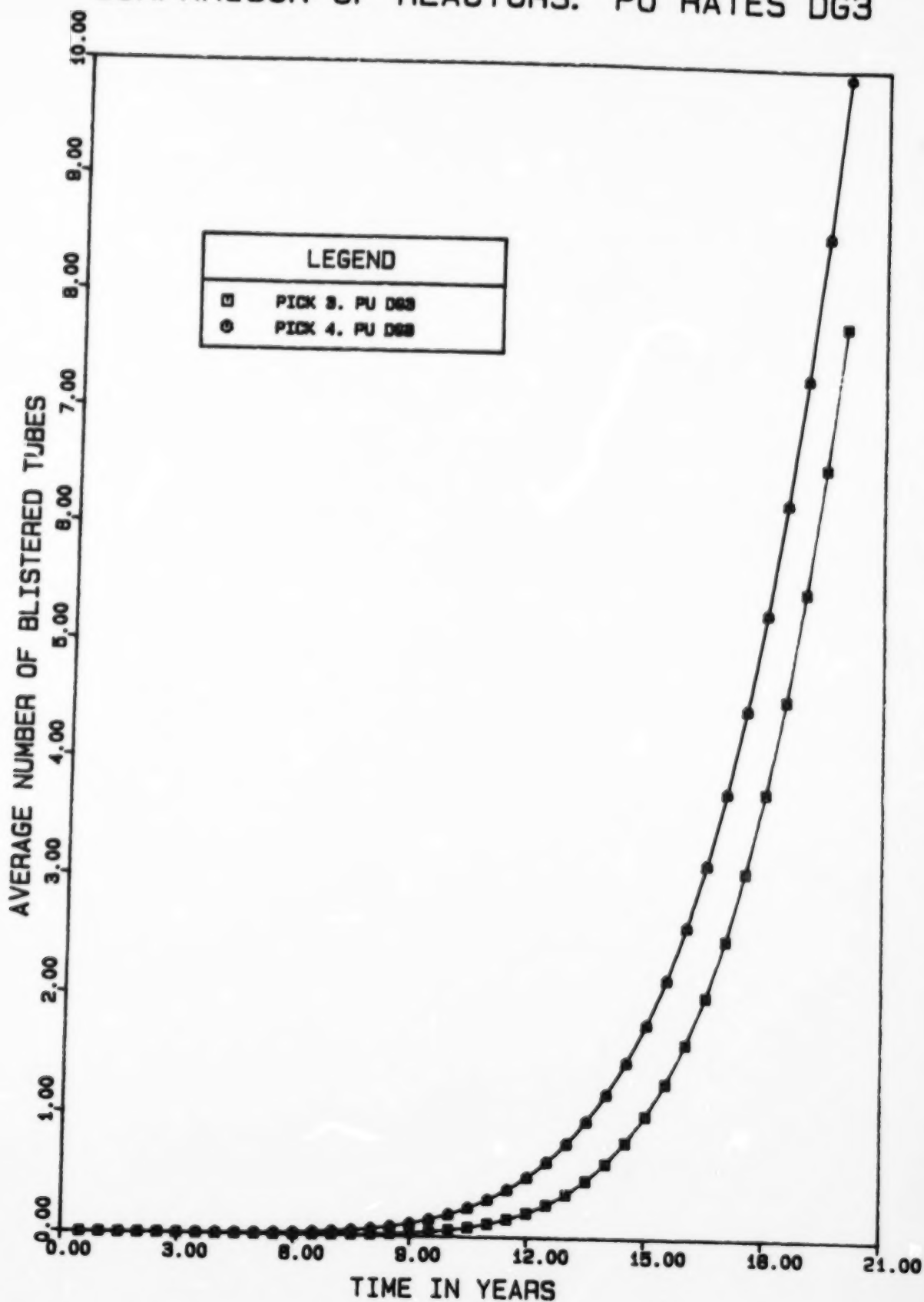


FIGURE 3

COMPARISON OF THRESHOLDS: PU RATES BW

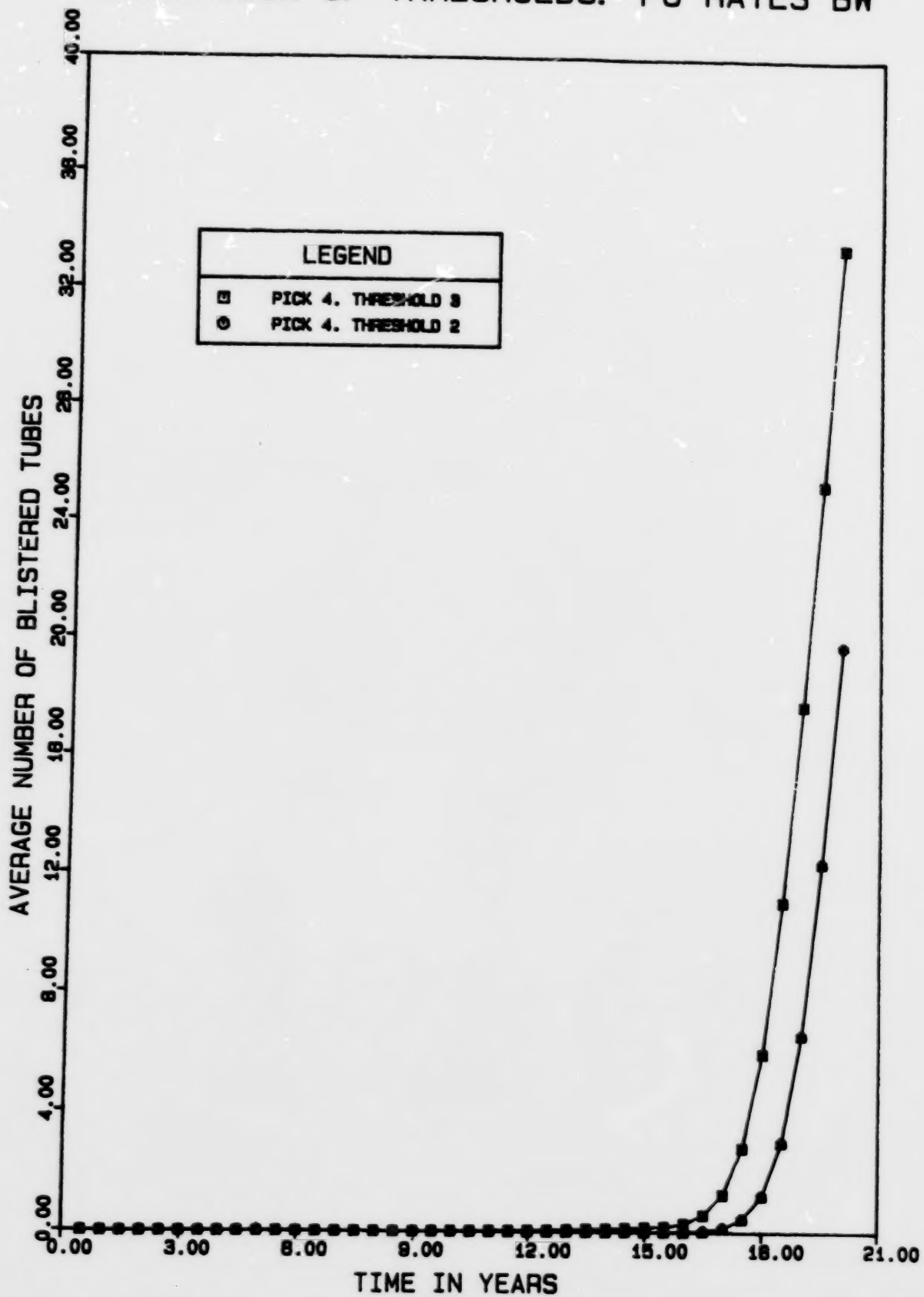


FIGURE 4

APPENDIX 1 - HYDROGEN THRESHOLD

The treatment of this variable is identical to the treatment presented in the previous report/1/. The change in calandria tube thickness for Pickering reactors alters the PHT temperature-contact temperature relationship slightly. The other procedures are identical to the ones reported previously. In the following tables the threshold for scenario 3.0 (the most likely one) and scenario 2.0 (a more optimistic one) are tabulated.

TABLE 1.1

THRESHOLD FOR PICKERING 3 AND 4 (CENTRAL CORE) SCENARIO 3.0

AREA	PHT TEMP °C	CONTACT TEMP °C	HYDROGEN THRESHOLD	STANDARD DEVIATION
#1	257	207.5	20.7	3.25
#2	270	216.5	23.1	3.45
#3	285	227	26.2	3.88

THRESHOLD FOR PICKERING 3 AND 4 SCENARIO 2.0

AREA	PHT TEMP °C	CONTACT TEMP °C	HYDROGEN THRESHOLD	STANDARD DEVIATION
#1	257	214	24.7	3.25
#2	270	223.5	27.7	3.45
#3	285	234	31.2	3.88

References

1. M. Leger and D.V. Leemans, "A Study on Hydride Blister Formation in Bruce 3 and 4 and Pickering 5 and 6", Ontario Hydro Research Report 86-153-K, 1986.

APPENDIX 2 - INITIAL HYDROGEN CONTENT

For reactors Pickering 3 and 4, each lattice position was assigned the two values corresponding to the hydrogen measurements of the first and last tube from the same ingot as the tube at that particular lattice site/1/. The effect of this assignment is to weigh the measurements according to the number of tubes from each ingot in the reactor. The three reactor zones are treated independently. Weibull distributions were used to fit the data.

The results are shown in Table 2.1. It should be noted that small but real difference exists between the hydrogen content of Pickering 3 and of Pickering 4.

TABLE 2.1
INITIAL HYDROGEN DISTRIBUTIONS

REACTOR	ZONE	MEAN STANDARD (ppm) DEVIATION		Weibull Parameters		
				CUT-OFF	σ	n
Pickering 3	Central	4.83	2.25	0	5.46	2.25
Pickering 3	Intermediate	4.37	2.21	0	4.93	2.04
Pickering 3	Outer	4.22	2.26	0	4.76	1.95
Pickering 4	Central	5.32	3.02	0	5.98	1.8
Pickering 4	Intermediate	5.30	2.91	0	5.97	1.85
Pickering 4	Outer	5.58	2.79	0	6.30	2.1

References

1. Inter-office memo from R.G. Barton to M.W. Hardie and B.D. Warr, "Initial [H] Contents: P3/4 Pressure Tubes", 86-09-17, File Number NCCF 5.10.

APPENDIX 3 - HYDROGEN PICK-UP RATE

The hydrogen² pick-up rate is at present difficult to determine from the available data. In order to accommodate more complex hydrogen pick-up rate scenarios, two modifications were made to the computer program used in the earlier study:

1. The pick-up rate can be dependent on each area (inlet, middle, outlet) along the pressure tube.
2. The pick-up of hydrogen is assumed to be piecewise linear; the transition time and the slopes of the two linear portions are inputs. Only the slopes are random variables.

A recent report/1/, hereafter referred to as WCL, did an in-depth study on modeling and analyzing deuterium pick-up in reactor pressure tubes. It is the source document for many of the calculations that follow.

The initial hydrogen pick-up rate was determined on the basis of the observations of the WCL report (Page 28) which makes a distinction between high T (>275°C) and low T (<275°C) pick-up rates. These are assigned to area 3 and 1 along the pressure tube; the values for area 2 are found by linear interpolation. The standard deviation was calculated from the standard error on the mean pick-up rate. The parameters of the appropriate Weibull distribution were found by matching the first two moments.

TABLE 3.1 - INITIAL HYDROGEN PICK-UP RATES

AREA	AVERAGE PICK-UP RATE (ppm/year)	PICK-UP RATE STANDARD DEVIATION	Weibull Parameters		
			CUT-OFF	σ	n
#1	0.201	0.072	0.0	0.225	3.1
#2	0.22	0.094	0.0	0.249	2.5
#3	0.239	0.116	0.0	0.27	2.2

Recent memoranda/2,3/ point out the possibility that the pick-up rate increases quite drastically after a certain period. The data on P4K10 indicate that about 10 ppm was picked-up over thirteen years at a position 4.9 m from the inlet end. With this as given, a scenario was developed with a transition time (in area #3) of 10 years; this requires a secondary pick-up rate of 2.54 ppm/year in area 3 (the outlet end).

A method was found to estimate the transition times (t_n) and pick-up rates (PUR_n) in the other areas along the pressure tube (where n denotes area of the pressure tube). It is proposed that

2. All pick-up rates are stated in terms of 'hydrogen equivalent'.

both follow an Arrhenius type relationship with as B value 5400°K (see page 24 in WCL). This leads to the following relationships:

$$\frac{t_1}{t_3} = \frac{\text{PUR3}}{\text{PUR1}} = 1.66 \quad (1)$$

and

$$\frac{t_2}{t_3} = \frac{\text{PUR3}}{\text{PUR2}} = 1.30 \quad (2)$$

with PUR3 being the hydrogen pick-up rate at the outlet end of the pressure tube.

As a final assumption, the coefficient of variation for the secondary pick-up rates was assumed to be constant from scenario to scenario but dependent on the area of the pressure tube. An estimate of this coefficient of variation was derived from the fitting to a quadratic function (see page 28 in WCL). Weibull distributions were used to describe the secondary pick-up rates.

TABLE 3.2 - SECONDARY HYDROGEN PICK-UP RATES

SCENARIO	AREA	TRANSITION TIME (YEARS)	AVERAGE PICK-UP RATE (ppm/year)	WEIBULL PARAMETERS		
				CUTOFF	n	σ
PU RATE 10	1	16.6	1.53	0.0	2.4	1.73
	2	13.0	1.95	0.0	1.85	2.2
	3	10.0	2.54	0.0	1.55	2.82

A similar pick-up rate scenario (PU RATE BW) based on Reference 3 was developed. It assumes that slow linear hydrogen pick-up takes place until an oxide layer of fifteen microns is reached. The transition time depends on temperature and therefore on location along the pressure tube. Transition times for inlet, middle and outlet were calculated to be 22 years, 18.8 years and 15.6 years respectively. At times larger than the transition time a pick-up rate of 5.25 ppm/yr equivalent hydrogen is postulated.

The other pick-up scenario is based on the relationship between iron content and pick-up rate as reported elsewhere/4/. A linear relationship is postulated between iron content (in ppm) and pick-up rate; this is consistent with some of the observations.

In order to develop a probability distribution for pick-up rates based on this idea the following steps were taken:

1. An iron concentration probability distribution was developed for each zone for each reactor that is investigated in this report. The iron concentration for each ingot is determined by averaging the top, middle and bottom values. Each tube is assigned the iron concentration of the ingot. A Weibull distribution was used to represent the iron concentration in each zone.
2. The linear relationship between iron concentration and pick-up rate is taken from reference 4 and can be represented by

$$\text{Pick-up rate in Area 3 (in ppm/year)} = .024 + .000853 \times [\text{Fe}] \text{ (in ppm)}$$

From this relationship and the Weibull distribution for iron, a Weibull distribution for the pick-up rate in area 3 can be constructed.
3. The pick-up rates observed in P4K10 in each area were used to infer the pick-up rates in the inlet and middle area from the estimate of the pick-up rate in the outlet area. This scenario (referred to as PU RATE DG3) results in the following ratios of pick-up rates for the three areas.

$$\frac{\text{PU}_3}{\text{PU}_2} = 1.75 \text{ and } \frac{\text{PU}_3}{\text{PU}_1} = 3.$$

The characteristics of the hydrogen pick-up rate distribution for Pickering 4 are given in Table 3.3.

TABLE 3.3
HYDROGEN PICK-UP RATES IN PICKERING 4 BASED ON IRON CONCENTRATION

SCENARIO	ZONE	AREA	AVERAGE PUR (ppm/year)	WEIBULL PARAMETERS		
				CUTOFF	σ	n
DG3	Central	1	0.253	0.065	0.209	3.4
		2	0.433	0.111	0.358	3.4
		3	0.757	0.195	0.626	3.4
	Intermediate	1	0.255	0.065	0.211	3.7
		2	0.438	0.111	0.362	3.7
		3	0.767	0.195	0.634	3.7
	Outer	1	0.257	0.065	0.213	3.5
		2	0.438	0.111	0.364	3.5
		3	0.769	0.195	0.638	3.5

References

1. B.D. Warr, A.M.C. Chan and S.R. Lukac, "Modeling Corrosion and Deuterium Pick-up in Operating Reactor Pressure Tubes", Ontario Hydro Research Report, #86-151-K.
2. D.D. Coleman, CNS Information Bulletin, 86-10-22.
3. Memorandum of B.D. Warr and M. Hardie to REFAB Task Force, "Predictions of Equivalent Hydrogen Levels in Pickering 3 and 4 Pressure Tubes", File #827.22, October 2, 1986.
4. Memorandum of R. Barton, "P 3/4 Equivalent [H] Predictions", 86-11-03.

APPENDIX 4 - RELATIONSHIP BETWEEN SPAN LENGTH AND TIME TO CONTACT

A set of master curves was developed on the basis of the work of Sakagachi/1/ and Hardie/2/ using the ABAQUS computer code. The curve pertaining to the inlet area was obtained by scaling the outlet curve by a factor (1.52) deduced from the work on Bruce 6 and Pickering 7. In order to estimate the time to contact for channels in the intermediate and outer zones, the procedure developed in our previous report based on the work of V.W. Yu/3/ was used.

References

1. Memorandum of R.L. Sakagachi to R.Y. Lior/M. Hardie, "REFAB Assessment: Contact Predictions for Sample of 28 P3/P4 Fuel Channels", File #907-NA44-31100P, January 21, 1987.
2. Memorandum of M.W. Hardie to REFAB Task Force, "Pressure Tube - Calandria Tube Contact in Pickering Units 3 and 4. Work Package No. 10", File #907-NA44-31100P, January 23, 1987.
3. V.W. Yu, "Predictions of Pressure Tube to Calandria Tube Contact in PNGSA Units 3 and 4", Ontario Hydro, Nuclear Systems Department, Report #84-3392, November 1984.

APPENDIX 5 - TREATMENT OF GARTER SPRING LOCATIONS

In the study dealing with blister formation in Bruce 3 and 4 and Pickering 5 and 6/1/, the databases for garter spring locations in Bruce 6 and Pickering 7 were used to model the garter spring locations in Bruce 3 and 4 and Pickering 5 and 6 respectively. Such extensive databases are not available for Pickering 3 and 4; Only 28 sets of garter springs location data in Pickering 3 and 4 are available.

Other workers in the field have pointed to the difficulties involved in fitting a distribution to the observed garter spring locations/2,3/. Two of the problems are the observed, large peaks in the distributions at the design locations and the asymmetry in the displacements. Therefore, a careful analysis was carried out.

The first step in the analysis was to simplify the data by categorizing each observed garter spring location as positive (outboard), zero (design location ± 5 cm), negative (inboard). Care was taken to keep the information regarding East-West and inlet-outlet intact.

The results of this analysis indicated the following:

1. The databases of Pickering 3 and Pickering 4 can be merged; the differences are considered minor.
2. A difference was noticed between East and West inlets. This resulted in a different treatment for these two types of inlets. Directional probabilities are established for each.
3. A correlation table between inlets and outlets was established to preserve the correlation in displacements (which was also observed in reactors with four garter springs).

The previous observations resulted in the following procedure for establishing an appropriate garter spring distribution.

1. Attention is first paid to the inlet garter spring. A distinction is made between an east and a west inlet; the direction is obtained from a random process with the appropriate probabilities. The magnitude of the displacement (in the case of non-zero direction) is then obtained from sampling from an exponential distribution with the appropriate parameter.
2. The direction of the outlet garter spring is determined from the correlation probability table (again in random fashion). The magnitude of the displacements is taken in a fashion similar to the inlet garter springs.

The resulting distribution results in a large number of situations with both garter springs in the design locations (slightly less than 50%).

Figure A5.1 displays the cumulative probability of the inlet garter springs for Pickering 3 and 4. Both the observed and the proposed distribution are shown. The difference between the two for the inlet springs can be explained on the basis that more east inlets than west inlets were present

in the observed sample; as pointed out above, they behave differently. This fact results in an under-representation of the number of garter springs at the design location in the observed distribution. With this in mind, the fit between the observed distribution and the proposed one is satisfactory.

References

1. M. Leger and D.V. Leemans, "A Study on Hydride Blister Formation in Bruce 3 and 4 and Pickering 5 and 6", Ontario Hydro Research Report 86-153-K, 1986.
2. J. Brimberg, "Statistical Analysis for Pressure Tube to Calandria Tube Contact Times and Garter Spring loads for Pickering Units 5 to 8 and Bruce Units 5 to 7". AECL Engineering Company (1985/04/04).
3. Memorandum, M.W. Hardie to REFAB Task Force, "Preliminary Analysis of Pickering A Garter Positions REFAB Assessment Work Package No. 10", File #907-N31100P, September 22, 1986.

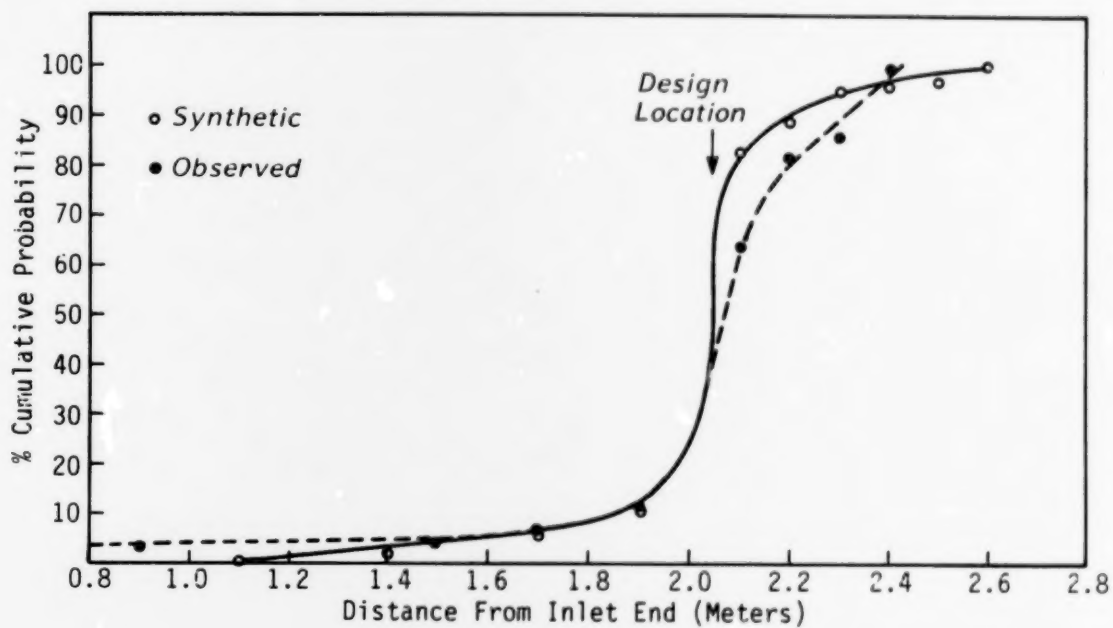


FIGURE 5
INLET CARTER SPRING DISTRIBUTION PICKERING 3 & 4

DISTRIBUTION

Mr. D.W. Souther	Design & Development - Gen, H10A1
Dr. G.J. Field	Design & Development - Gen, H10A16
Mr. M.W. Hardie	Design & Development - Gen, H10C16
Mr. M. Natesan	Design & Development - Gen, H10B7
Mr. E.J. Bennett	Design & Development - Gen, H10A4
Mr. H. Goulding	Design & Development - Gen, H10F11
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